ANATOMICAL SPECIFICITY OF SEPTAL PROJECTIONS IN ACTIVE AND PASSIVE AVOIDANCE BEHAVIOR IN RATS

by

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The behavioral effects of septal lesions have been intensely investigated in recent years. Experiments encompassing wide ranges of test conditions and laboratory species have implicated the septum in a broad spectrum of psychological and physiological phenomena. The lesion induced effects, as reviewed by McCleary (1966), include hyperirritability or hypersensitivity, enhanced performance on active avoidance, and decrements on passive avoidance, timing, alternation, and position reversal.

The septum of rodents and carnivores, the principal species investigated, is complex. It is composed of at least four major nuclear divisions (Andy & Stephan, 1964 and Raisman, 1966). Large septal lesions often involve all of the various nuclei and their afferents and efferents, as well as numerous fibers originating near, or in transit around the septum. These include among others, the fornix, stria medullaris, stria terminalis, anterior commissure, and diagonal bands of Broca. Since these are all related anatomically to the septum, it has been difficult to assess their contributions to the diverse behavioral components associated with large septal lesions.

Septal output is composed of a telencephalic and diencephalic projection. The former originates in the medial septum and projects via the fimbria and fornix to the posteroventral and anterodorsal hippocampus (Powell & Cowan, 1955 and Raisman, Cowan & Powell, 1966). The diencephalic projection has a dorsal and ventral division. Dorsal efferents originate in the lateral septum (Nauta, 1960) and septofimbrial nucleus (Raisman, 1966) and project via the stria medullaris to the habenular nuclei, or bypass these to end in the central grey and interpeduncular nucleus. Ventral diencephalic projections originate from all areas of the septum and join the medial forebrain bundle to terminate in the hypothalamus (Raisman, 1966). These projection pathways also carry fibers afferent to the septum, with the possible

exception of the stria medullaris. Anatomically septal projections have attracted wide interest because of their consistency across wide phylogenetic levels, but little is known about them behaviorally or physiologically.

Attempts to make delimited lesions within the septum, in hopes of anatomically specifying those areas responsible for the observed behavioral changes have not been successful (Harrison & Lyon, 1957; Lyon & Harrison, 1959; Kenyon & Krieckhaus, 1965; Thomas & Van Atta, 1966). A more valuable method for accomplishing this end, as well as dissociating anatomical overlap within the septum, is suggested by the work of Fischman and McCleary (1966). They found that complete fornicotomy in cats led to some aspects of the behavior seen with septal lesions, but not others.

The purpose of the present study was to selectively interrupt fiber tracts originating from or receiving septal components. Thus the effects of septal, fornix, and stria medullaris-habenular lesions were compared on a food reinforced passive avoidance task, and on the acquisition, retention, and extinction of a two-way shuttlebox avoidance task.

METHOD

Subjects

The Ss were 96 male Long Evans Hooded Rats, 120 days old, weighing 300-350 gms., and purchased from Rockland Farms, Gilbertsville, Pa. All were housed individually in wire cages with ad-lib food and water except for a brief period of food deprivation during the passive avoidance phase of the experiment.

Apparatus

A two-way automated shuttlebox with 3/8 in. plexiglass walls was used. Dimensions were 24 X 18 X 8 in. with a plexiglass barrier 2 1/2 in. high

dividing it into two equal compartments. The floor consisted of 1/4 in. stainless steel bars 3/4 in. apart. Compartment grids could be independently electrified. The shuttlebox was housed inside a sound attenuating chamber and was ventilated by a blower which also provided a constant masking noise of 65 db. (re: .0002 dynes/cm.^{2}). The CS was a buzzer mounted 10 in. above the center of the shuttlebox. It provided a sound 2 db. above background. The UCS was a 0.5-ma. ac scrambled footshock.

The passive avoidance apparatus was the same shuttlebox, but had the following modifications. A 12 in. high guillotine door was mounted directly over the barrier. Pulleys allowed E to raise and lower it. Additionally, a metal food cup was mounted 3 in. above the grid of one compartment end, and could be electrified with 0.25-ma. ac from a shock generator. A one-way window in the sound attenuating chamber allowed E to observe and control the passive avoidance procedure. Latencies were recorded with a stop watch. Both active and passive avoidance were conducted under dim illumination, provided by a pair of 5-w. lamps centrally located behind the shuttlebox.

Surgery and Histology

All Ss were chosen at random from a larger laboratory population and given either septal, fornix, stria medullaris-habenular lesions, or allowed to remain normal. Since the stria medullaris-habenular complex is embedded in the dorsal thalamus, additional Ss received dorsal medial thalamic control lesions. Surgery was performed with Nembutal anesthesia (50 mg./kg.) and atropine to suppress mucosal secretions. Post-operatively 45,000 units of Bicillin were administered. Bilateral electrolytic lesions were made with anodal dc at the uninsulated tip of a steel electrode inserted stereotaxically into the brain. An anal cathode completed the circuit. Measurements were made in mm. from bregma, midline, and top of the skull, with a head angle of

5° relative to the interaural line. Lesion coordinates and parameters were as follows: septum, 1.5 A, 0.5 L, 6.0 D, with 1.5 ma. for 20 sec., stria medullaris-habenular, 1.8 P, 0.4 L, 5.6 D, with 1.0 ma. for 12 sec., fornix, 0.5 P, 1.0 and 1.4 L, 4.0 and 4.4 D, with 1.0 ma. for 15 sec., dorsal medial thalamic, 1.6 P, 0.0 L, 6.4 D, with 1.5 ma. for 20 sec.

After testing Ss were sacrificed with an overdose of Nembutal and perfused successively with 0.9% saline and 10% formalin. After removal, brains were embedded in celloidin and sectioned frontally at 12 μ. Every fifth section was stained with cresyl violet. Additional sections through the lesion were counterstained with luxol fast blue.

Procedure

Passive Avoidance: Four days after surgery Ss were placed on a 23 hr. food deprivation schedule. Four days later passive avoidance training and testing began. On the first two days Ss were placed in the apparatus to allow adjustment of walking on the grids, raising and lowering of the guillotine door, and eating from the food cup. Training trials were given on the third, fourth, and fifth days. These were initiated by raising the guillotine door and allowing S to cross into the goal compartment and eat the single 45 mg. Noyes food pellet previously placed in the food cup. When S did not return promptly after eating, E forced him gently across the barrier to the start compartment with a small paddle. Twenty trials were given daily. After 35 training trials two restrictions were imposed. First, a 15 sec. intertrial interval (ITI) began, and secondly, S was allowed only 60 sec. to respond after the guillotine door had been raised. Response latencies, approaches, and eating occurrences were recorded. Response latencies were defined as the time elapsed after raising the guillotine door until S fully crossed the barrier with all four feet. Approach responses were defined as

fully crossing the barrier, but returning voluntarily to the start side without eating, or fully crossing the barrier, but not eating within the 60 sec. allowed. After five regular training trials on the sixth day, the food cup was electrified for five trials and Ss received a shock upon touching it. During these trials they were allowed the usual 60 sec. to respond and eat. After every shock received Ss were forced back to the start side of the apparatus if needed and a new ITI initiated. If they failed to respond the guillotine door was lowered starting the next ITI and a 60 sec. response latency was recorded. Fifteen post-shock test trials were conducted immediately, and on the subsequent day. These were exactly like training trials and terminated the passive avoidance phase of the experiment.

Active Avoidance: Following passive avoidance testing Ss were returned to an ad-lib food schedule. Three days later active avoidance training began. A standard two-way shuttlebox procedure was used, with a 30 sec. ITI. On all trials the CS was presented for 10 sec. followed by the UCS. If S crossed to the opposite compartment before the UCS an avoidance response was recorded, otherwise an escape response was recorded. In both cases the CS was response terminated. Total intertrial responses (ITR's) were also recorded. A criterion of 22 out of 25 avoidance responses across daily sessions of 25 trials was used. If Ss failed to reach this in 200 trials no additional testing was given.

Retention: Eight days after Ss reached the active avoidance criterion testing for retention of active avoidance began. The same procedure and criterion, as described above, was used.

Massed Extinction: On the first day following retention criterion, extinction trials began. The ITI was reduced to 12 sec. for all trials. If

Ss responded within 10 sec. after the initiation of the CS an avoidance response was recorded and the CS terminated. If they failed to respond the CS terminated after 10 sec. and the next ITI began. On all trials the UCS was omitted. Five daily sessions of 25 trials were conducted, followed by the sacrifice of all Ss.

All Ss were run first on the passive avoidance task, followed by the active avoidance task. Post-operatively trained Ss were given an 8 day rest period following active avoidance criterion, than run on retention of active avoidance and massed extinction. Normal Ss upon reaching the active avoidance criterion were given either septal or stria medullaris-habenular lesions, or allowed to remain normal. They were then run on retention of active avoidance and massed extinction. The effects of fornix lesions on retention was not investigated. Ten normal Ss used in the retention phase of the experiment were not run on passive avoidance.

RESULTS

Histology

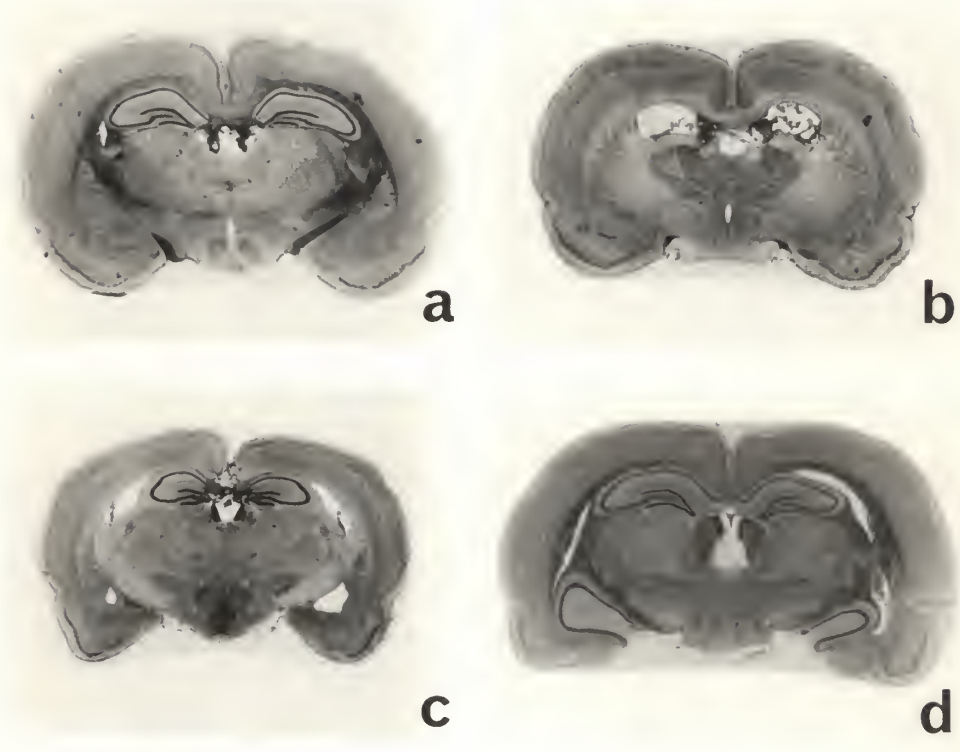
Photomicrographs of representative lesions are shown in Figure 1. All histological analyses and groupings were done without previous knowledge of the behavioral results.

Nine Ss sustained major destruction of the lateral and medial septal nuclei. These Ss were classified as anterior septals, not unlike numerous others described in the literature. Damage typically started just rostral to the genu of the corpus callosum and encompassed the anterior two thirds of the septum.

The attempts to make discrete stria medullaris-habenular lesions with little secondary damage to other structures were successful in a relatively

Figure Caption

Fig. 1. Photomicrograph showing representative destruction through the major extent of the lesion, (a) stria medullaris-habenular, (b) fornix, (c) lesion control, (d) dorsal medial thalamic.


a
b
c
d

small number of cases. Out of 34 attempts, only 10 Ss suffered 80% or more destruction of the stria medullaris, habenular nuclei, or both. The remaining Ss had small lesions encroaching principally upon the anterodorsal hippocampus, corpus callosum, and posterior cingulate cortex. Six of these Ss had unilateral medial habenular nucleus damage. In almost all cases these unsatisfactory lesions were caused by either insufficient depth penetration of the electrode, or by lateral placements too near the third ventricle. Since damage in these Ss was similar to the secondary damage accompanying the 10 successful or satisfactory stria medullaris-habenular lesions, they were placed in a lesion control group.

Fourteen Ss received major fornix destruction. In four cases there was complete transection of the dorsal fornix and more laterally lying fimbria. Others received variable amounts of damage amounting to 60-70% destruction in all but four cases. In some Ss with partial destruction, the remaining fimbria was often collapsed and gliotic, lying on the floor of the ventricle. Dense gliosis anterior and posterior to the lesion accompanied all fornix damage. Small amounts of secondary damage occurred to the posterior cingulate cortex, anterodorsal hippocampus, and corpus callosum. Fornix lesion were intentionally placed caudally to avoid damaging septo-habenular fibers which, as Nauta (1960) reported, travel for a short distance in the descending columns of the fornix before joining the stria medullaris.

Dorsal medial thalamic control lesions were variable. Some were extensive, encompassing all of the dorsal medial nucleus, posterior aspects of the habenular nuclei, parafasicular nuclei, and descending habenulo-peduncular tracts. In some Ss additional damage occurred to the posterior commissure and superior colliculus. Others received only small dorsal medial nucleus damage, completely sparing the habenular nuclei and habenulo-peduncular

tracts. This group was not included in the data analyses because of the large degree of lesion variability. Instead, they are discussed individually.

Of the normals receiving lesion treatment for the retention phase of the experiment, 6 Ss received similar septal lesions as previously described and 5 Ss received similar stria medullaris-habenular lesions. A lesion control group was formed with those not receiving extensive damage to the stria medullaris or habenula in a similar manner as discussed previously.

Passive Avoidance

Treatment effects, means, and group N's are summarized in Table 1, and depicted graphically in Figures 2 and 3. Winer's (1962) unweighted means analysis of variance for unequal group sizes was used for variables with a repeated measure, and a single classification analysis of variance (ANOVA) for all others. Mean comparisons were by t test (McNemar, 1961) in which the ANOVA mean square error is used as the best estimate of error variance for all groups.

ANOVA of total eating occurrences revealed a significant treatment effect, days effect, and T X D interaction. Mean comparisons revealed that septals and stria medullaris-habenulars returned to eat significantly more ($p<.001$) than fornix, lesion control, and normal groups on the total post-shock trials. Septals and stria medullaris-habenulars did not differ from each other, or did lesion control and normals. The fornix group had intermediate performance, differing from normals ($p<.01$) but not from lesion controls. For only those trials immediately following shock, similar group differences were observed, however fornix Ss did not differ from normals on these trials.

As shown in Figure 2, the differences in lesion induced decrements on the eating measure were greatest on those trials immediately following shock.

Table 1. Mean Performance, F Ratios, and Group N's

Group	N	Passive Avoidance			N	Active Avoidance			N	Extinction
		Post-Shock Eating				Post-Shock Latency								
		Total	Blocks 4,5,6	Blocks 7,8,9		Total	Blocks 4,5,6	Blocks 7,8,9		Trs. to Crit.	% Tot. Avoid.	Err/5 Trials		% Avoid.
Septal	9	24.7	10.3	14.3	9	21.7	18.7	3.0	9	44.4	72.4	2.0	9	83.8
S.M. Hab.	10	22.1	8.0	14.1	10	37.0	26.8	10.2	10	50.5	73.3	3.0	10	71.7
Fornix	14	11.9	2.2	9.7	14	60.1	42.1	18.3	14	32.5	85.2	4.5	14	74.4
Lesion Control	18	9.1	1.2	7.9	18	79.2	51.6	27.6	18	107.5	54.1	0.9	14	46.3
Normal	18	5.3	0.6	4.7	29	92.9	52.9	40.0	29	87.9	47.6	0.9	6	29.2
ANOVA	df	4/68	4/68	4/68		4/68	4/68	4/68	df	4/79	4/79	4/79	df	4/52
ANOVA	F	*** 17.9	*** 21.2	*** 9.3		*** 15.2	*** 13.4	*** 9.4	F	*** 12.2	*** 21.1	*** 8.63	F	** 4.64

***p < .001
**p < .01

Septal and stria medullaris-habenulars returned quickly to pre-shock eating levels, while eating occurrences for the other groups remained low. On those trials conducted on the day following shock trials, all groups returned substantially more often to eat, but only the fornix group exceeded the level obtained by the septal and stria medullaris-habenular groups on the previous day. The post-shock eating occurrences of the dorsal medial thalamic controls seemed correlated with the amount of habenular and habenulo-peduncular tract damage. Those Ss having only dorsal medial nucleus damage (N=2) were not different from normals. Those having a large lesion including habenular and habenulo-peduncular tract damage (N=5) were intermediate in their performance, falling between the lesion control and fornix groups.

As would be expected, similar group differences as for eating occurrences were also found for response latencies. A significant treatment and days effect was observed for total response latencies, but no T X D interaction occurred. As shown in Figure 3, the greatest lesion induced differences occurred on trials immediately following shock. The performance plateau of the fornix Ss on these trials does not resemble other groups. It should be re-emphasized, however that response latencies were defined as the total time elapsed between the raising of the guillotine door and Ss subsequent crossing the barrier with all four feet. Thus, a low latency could be obtained by crossing promptly than returning to the start side without eating, or by merely waiting in the goal compartment until the trial elapsed. Three fornix Ss had a large number of approach responses during those trials immediately following shock, which accounts for this plateau. Eating occurrence was a much more sensitive measure of the Ss ability to withhold responding in light of the procedure employed.

No overall treatment effect was observed for total shocks taken or for

Figure Caption

Fig. 2. Mean percent eating occurrences per group across five trial blocks. Blocks 1 & 2 = pre-training, Block 3 = percentage of five available shocks received, Blocks 4, 5 & 6 = test trials immediately following shock, Blocks 7, 8 & 9 = test trials on the day following shock.


100
90
80
70
60
50
40
30
20
10
0
% EATING OCCURENCES
1
2
3
4
5
6
7
8
9
FIVE TRIAL BLOCKS
Septal
Stria Medullaris
Fornix
Lesion Control
Normal

approach responses.

Active Avoidance

As summarized in Table 1, a significant treatment effect was observed for trials to criterion, percent avoidance responding, and ITR's per five trial block. Mean comparisons revealed that septal, stria medullaris-habenular, and fornix groups all had significantly ($p<.001$) enhanced acquisition performance, taking less trials to reach criterion than lesion controls. Additionally, fornix Ss differed from normals ($p<.001$) as did septals and stria medullaris-habenulars ($p<.01$). Experimental lesion groups did not differ from one another or did normals and lesion controls. Those Ss with small dorsal medial thalamic lesions were not different from normals, while those with large lesion did very poorly, failing in most cases to reach criterion in the trials allowed.

Mean comparisons for percent avoidance responding revealed that septal, stria medullaris-habenular, and fornix groups made significantly more avoidance responses ($p<.001$) than either normals or lesion controls. Septal and stria medullaris-habenulars did not differ from one another, but fornix Ss did differ from both ($p<.05$) making the highest percentage of avoidance responses of all groups. Lesion controls and normals did not differ.

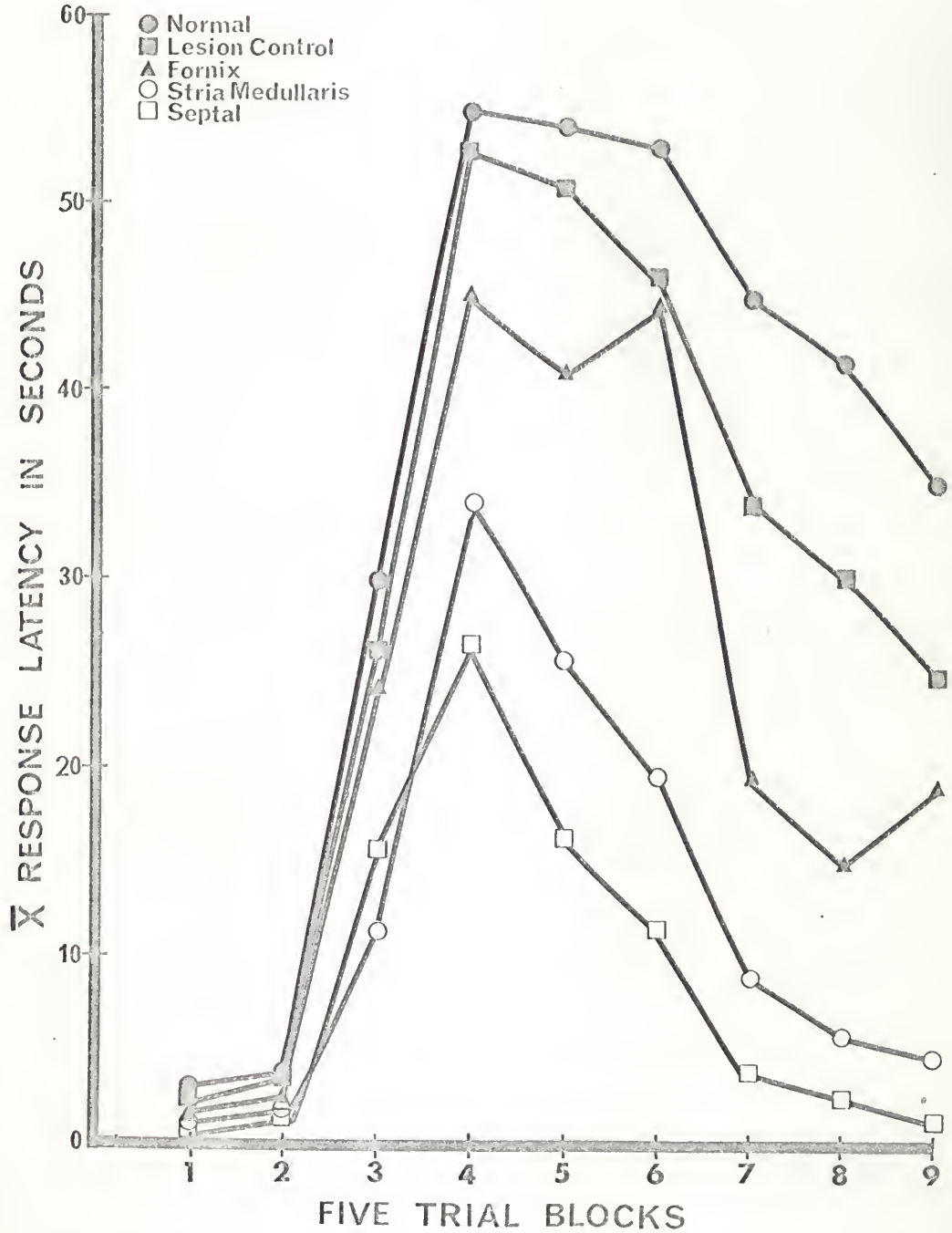
Mean comparisons of the average number of ITR's per five trial block of acquisition trials showed that fornix Ss differed significantly from normals and lesion controls ($p<.001$) and from septals ($p<.01$). They did not differ from stria medullaris-habenulars. The latter group differed from normals and lesion controls likewise ($p<.05$) but did not differ from septals.

Retention

ANOVA of trials to criterion for the retention of active avoidance revealed no significant treatment effect between any groups, whether

Figure Caption

Fig. 3. Mean response latency per group in seconds across five trial blocks. Blocks L & 2 = pre-training, Block 3 = shock trials, Blocks 4, 5 & 6 = test trials immediately following shock, Blocks 7, 8 & 9 = test trials on the day following shock.


Normal
Lesion Control
Fornix
Stria Medullaris
Septal
60
50
40
30
20
10
0
X̄ RESPONSE LATENCY IN SECONDS
1
2
3
4
5
6
7
8
9
FIVE TRIAL BLOCKS

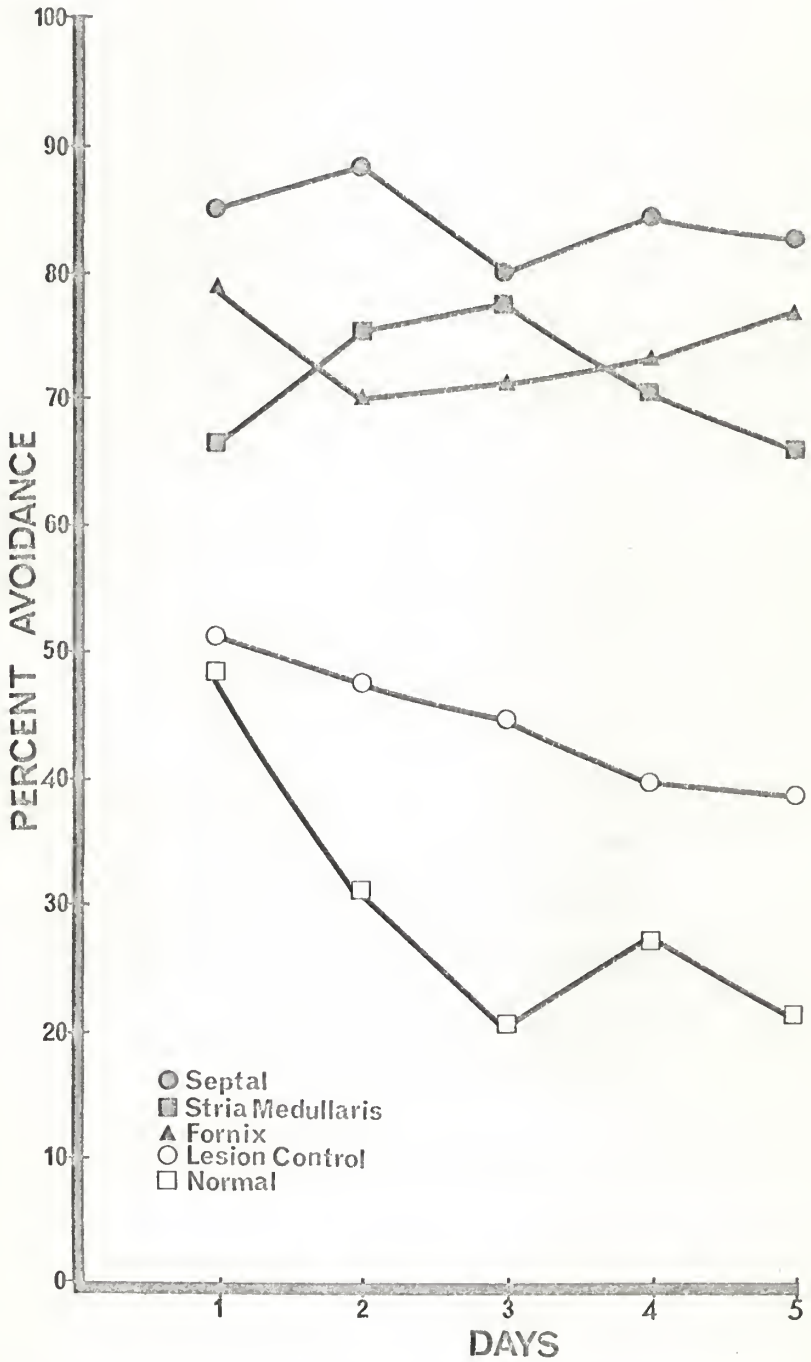
pre-operatively or post-operatively trained.

Massed Extinction

As summarized in Table 1, a significant treatment effect was observed for this variable. No days effect or T X D interaction was found. This data is graphically presented in Figure 4. Septals made a significantly greater ($p<.01$) number of avoidances than normals and lesion controls. Likewise, fornix and stria medullaris-habenulars differed significantly from normals ($p<.01$) and lesion controls ($p<.05$). The control groups did not differ from each other. Since the shortening of the ITI suppressed ITR's for all groups these measures were not calculated.

Figure Caption

Fig. 4. Mean percent avoidance responding per group across daily massed extinction sessions.


100
90
80
70
60
50
40
30
20
10
0
PERCENT AVOIDANCE
1
2
3
4
5
DAYS
Septal
Stria Medullaris
Fornix
Lesion Control
Normal

DISCUSSION

In agreement with previous investigations, septal lesions enhanced performance on two-way shuttlebox avoidance, (King, 1958 and McCleary, 1961) and led to decrements on passive avoidance (McCleary, 1961). Septals showed variable degrees of sensitivity and irritability, with some being very difficult to handle and other not. This was not correlated with either the behavioral measurements or histological results and agrees with Kenyon and Krieckhaus's (1965) observation that the occurrence of the so-called septal syndrome is not a prerequisite of enhanced active avoidance performance.

On the passive avoidance task, the septals reaction to shock was an increase rather than a decrease in activity. On post-shock trials they often explosively leaped the barrier, ate, than returned in a similar manner to the start side of the apparatus without E having to force them back. These Ss typically appeared frightened and would react noticeably to E's movements in replacing the food pellet. Fearfulness did not seem to be specifically related to the food cup as it was in normals.

Of principle interest is the finding that stria medullaris-habenulars did not differ from septals on any measure investigated in this study. Although no studies have systematically investigated the effects of this lesion on avoidance performance, this result might not be expected from other related studies. Brady and Nauta (1955) found habenular lesions not to interfere with the acquisition of a conditioned suppression response, while septal lesions led to very little suppression. This study does not seem comparable to the present on histological grounds. As Brady and Nauta (1955) emphasize, their lesions were often small and unilaterally placed. Since the stria medullaris courses through the habenular nuclei in three separate bundles, the largest of which is positioned dorsolaterally, a small lesion would leave a major

portion of this complex intact. In the present investigation lesions typically started near the most anterior aspect of the medial habenular nuclei and often severed the stria medullaris before it actually entered these nuclei. Even those lesions placed directly in the habenular nuclei were of sufficient extent to destroy both nuclear groups and stria medullaris fibers embedded within and on the nuclear perimeters.

Davis, Stevenson, McIver, and Neilson (1966) found habenular lesions not to interfere with the acquisition of a passive avoidance response when Ss were required to remain on an elevated platform over an electrified grid. The results of the present study do not support this finding, however it is possible that the step-off task employed by these investigators is not sensitive to the lesion induced decrements observed in the acquisition of a passive avoidance response. Kimble, Kirby, and Stein (1966) found this task to be insensitive to large hippocampal lesions, which, when other tasks are employed, result in passive avoidance deficits.

Davis, McIver, and Neilson (1966) and Neilson and McIver (1966) found habenular lesions seriously impaired the acquisition of a conditioned avoidance response. The apparatus used in both investigations was somewhat novel, consisting of an elevated T maze with levers in each arm, and a grid floor through which footshock could be delivered. The Ss task was to respond to the spatial position opposite their position choice and press the lever to terminate footshock. Habenular Ss were reported to have had extreme difficulty in reversing their initial position choice and perseverated markedly on all trials. Neilson, McIver, and Boswell (1965) obtained the same results with septal lesions on this task. As discussed by McCleary (1966), the septal deficit on this modified active avoidance task is not surprising since it contained a position reversal component. Numerous studies have shown that

septals perseverate in such situations. Of principal interest is the similarity between septal and habenular groups on this task, and on the measures investigated in the present study.

Stria medullaris-habenulars were extremely active, continually investigating and exploring the apparatus throughout all test sessions. This observation agrees with those reported by Davis et al. (1966), who found enhanced exploratory behavior with habenular lesions. Like septals, stria medullaris-habenulars were greatly excited by shock in both active and passive avoidance situations. Although the septal and stria medullaris-habenular groups did not differ on the variables investigated in this study, striking differences in their behavior were observed and should be emphasized. No stria medullaris-habenular S was irritable or sensitive. All could be handled relatively easily and were not aggressive. They were responsive to tactile stimulation on the back or tail, but not explosive in their reactions as some septals were. Additionally, they did not exhibit a startle reaction to E's movements in replacing the food pellet or returning them to the start side of the apparatus during the passive avoidance training and testing. Greater home-cage activity was also noted, in contrast to septals who would often sit immobile for long periods of time.

Unusual motor behavior was noted in only the stria medullaris-habenulars. Typically, when responding in the passive avoidance situation, they would climb onto the barrier, than leap off in a quick jerky manner, landing on all four feet. This was in contrast to the smooth bipedal crossing and jumping observed in other groups. Four of the ten stria medullaris-habenulars attempted to jump out of the apparatus during the ITI of post-shock passive avoidance trials. These Ss did not appear frightened, as evidenced by the fact that they would respond and eat promptly when the guillotine door was

raised. This unusual behavior seemed more associated with their extreme hyperactivity, than with fearfulness.

It is unlikely that the behavioral effects observed with stria medullaris-habenular lesions were caused by incidental or secondary damage to other structures even though consistent anterodorsal hippocampal and dorsal medial thalamic damage occurred in all Ss. Kimura (1958) and Kaada, Rasmussen, and Kveim (1962) found anterodorsal hippocampal lesions to have no effect on the acquisition of a passive avoidance response. Similar findings are reported for dorsal medial thalamic lesions by Kaada et al. (1962) and Gerbrandt (1965). Thomas and Otis (1958) found anterodorsal hippocampal lesions to lead to large deficits on active avoidance, as have Vanderwolf (1964) and Bohus and DeWeid (1967) for dorsal medial thalamic lesions. When these studies are examined with the control data collected in the present study, it is difficult to attribute the behavioral effects of stria medullaris-habenular lesions to anything but this crucial complex.

Fornix lesions have not been extensively investigated. Migler (1961) reported that the performance of Rhesus monkeys following fornix lesions could not be distinguished from normals on the acquisition of a DRL task. Additionally, Hostetter and Thomas (1967) found fornix damage not to interfere with the acquisition of a Hebb-Williams maze. In the most relevant study, Fischman and McCleary (1966) found complete fornicotomy in cats had no effect on food reinforced passive avoidance, but interfered with position reversals. In the present study fornix Ss had only an intermediate deficit on passive avoidance. They did not differ overall from lesion controls with small amounts of hippocampal damage, or even from normals on passive avoidance trials immediately following shock. They differed greatly from septal and stria medullaris-habenular groups on this task. This contrasts with their

active avoidance performance which was similar to, or even enhanced, in comparison with septals and stria medullaris-habenulars. On this task they took the fewest trials, as a group, to reach criterion and had a significantly greater number of ITR's and avoidance responses. These results suggest that the fornix system is at least as crucial, or even more so, than the stria medullaris system in accounting for the enhanced performance seen on active avoidance with septal lesions, but has little to do with the passive avoidance deficit. It is important to point out, however that a large number of fibers traveling in the fornix have their origin in the hippocampus, and as shown by Isaacson, Douglas, and Moore (1961) and Green, Beatty, and Schwartzbaum, (1967) large hippocampal lesions do result in enhanced two-way shuttlebox avoidance performance also. Thus it is difficult in the present study to attribute the observed effects to either one structure or the other, however in light of their reciprocal afferent and efferent connections one might expect that both are critical.

That fornix lesions do not lead to deficits on passive avoidance is not totally surprising when one considers the studies previously discussed, even though the majority of the fibers in the fornix are of hippocampal origin. The observation that large hippocampal lesions lead to passive avoidance deficits is not unequivocal. Kveim, Setekliev, and Kaada, (1964) have found that lesions limited solely to this structure do not lead to passive avoidance deficits. Additionally there is no effect when lesions are limited either to anterodorsal or posteroventral hippocampus, (Kaada et al., 1962). Thus, as pointed out by McCleary (1966), it has not been conclusively demonstrated that the passive avoidance deficit seen with hippocampal lesions does not result from damage to other structures. The present study suggests that neither septo-hippocampal or hippocampo-septal fibers are crucial, however

it is important to point out that a large number of hippocampal afferents and efferents exist in addition to those traveling in the fornix. Principal among these are temporo-ammonic connections with the entorhinal cortex. These, and not fornix connections may be the crucial pathways for the development of a passive avoidance response.

Fornix Ss were not difficult to handle and showed no heightened activity or exploratory behavior. On trials immediately following shock in the passive avoidance situation they would typically lay or sit on the start side of apparatus and only occasionally peer over or climb on the barrier. They seldom crossed to the goal side. This diminution in activity and responding sharply contrasts with that of the septal and stria medullaris-habenular groups.

The results confirm LaVaque's (1967) finding that septal Ss are resistant to extinction of active avoidance when trials are massed. In view of the similar performance between septal, fornix, and stria medullaris-habenulars on active avoidance it is not surprising that the latter two groups were likewise similar to septals on this task.

The behavioral effects of septal lesions have been interpreted in terms of the thesis that destruction of this area results in a loss of somatomotor response inhibition (McCleary, 1961). This behavioral hypothesis stemmed largely from the electrophysiological studies of Kaada (1951) who observed that stimulation of the subcallosal-septal area resulted in the inhibition of cortically induced movement, peripherally induced reflexes, and various ongoing autonomic responses. As reviewed by McCleary (1966), this hypothesis accounts for much of the data dealing with septal lesions. As discussed previously, the septum is an exceedingly complex structure within which there are many pathways. Necessarily lesions in this general area reflect the

disruption of a large number of neural systems. Consequently, a stable behavioral pattern suggestive of a unitary function can be hypothesized. The results of the present study do not support such a conceptualization. Instead anatomically defined areas of the septum, from which relatively specific projections originate, do seem to be dissociable in terms of their importance in the mediation of the behavioral tasks investigated. When considered separately, as McCleary (1966) suggests doing, only certain behaviorally defined effects are observed, which may or may not mirror the effects of a total septal lesion. Thus a more meaningful conceptualization of septal function which is in keeping with its anatomical organization is one in which discrete areas of the septum are only parts of larger anatomically integrated neural systems effectuating the mediation and modulation of a large number of behavioral acts. Recent histochemical studies (Krnjevic & Silver, 1965; Manocha, Shantha, & Bourne, 1967; Lewis & Shute, 1967) suggest that there is considerable pharmacological specificity associated with the anatomical specificity of septum. Recently, Hamilton, McCleary, and Grossman have shown that dissociable behavioral effects can be obtained by placing neurally active blocking agents in the septum of cats. Results of this nature plus the results of the present study suggest that septal function may ultimately be described in terms of behaviorally dissociable anatomical and pharmacological organization.

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ANATOMICAL SPECIFICITY OF SEPTAL PROJECTIONS IN ACTIVE AND PASSIVE AVOIDANCE BEHAVIOR IN RATS

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AN ABSTRACT OF A MASTER'S THESIS

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Lesions were placed in pathways anatomically associated with septal projections to assess their individual contributions to enhanced active avoidance performance and to passive avoidance deficits found after large septal lesions. Septal and stria medullaris-habenular lesions impaired performance on a food reinforced passive avoidance task, while fornix lesions had little effect. Septal, stria medullaris-habenular, and fornix lesions all enhanced two-way shuttlebox avoidance performance and led to greater resistance to extinction of this task with massed trials. These results suggest that the behavioral effects associated with septal lesions are differentially mediated over its projections. A unitary explanation of septal function is not supported.